

WATER WELL DRILLING METHODS

ROTARY DRILLING

Hydraulic drilling is fast becoming one of the most popular well drilling methods in Michigan. Mud rotary is widely used in the Lower Peninsula where substantial overburden exists, while air rotary rigs are found primarily in the Upper Peninsula and the few high bedrock areas of Lower Michigan.

The principle of rotary drilling is based upon a rotating drill stem made of lengths of drill pipe about 15 feet long. A bit is attached to a heavy stabilizer or drill collar at the end of the column of drill pipe. The extra weight and larger outside diameter of the stabilizer just above the bit helps to maintain a straight drill hole. The drill stem is hollow and has a drilling fluid of either mud or air circulating down the drill stem out through the nozzles in the bit and up along the outside of the drill stem. The rotating action of the bit breaks up the material and the drilling fluid carries the cuttings to the surface where they settle out in a mud tank.

Several types of bits are available to the rotary driller. The bit most generally used in Michigan is the tri-cone roller bit. The type and number of cutting teeth on the bit cones vary depending upon the type of formations to be penetrated.

The upper end of the drill stem is attached to a kelly on a table drive rig and swivel which are mounted on a large mast. Hydraulic controls lower or raise the drill stem and operate the rotary motion. When a hole has been drilled the full length of the kelly, the drill stem is raised, the joint between the kelly and drill pipe is broken, and an additional length of drill pipe is added. The drive mechanism for the drilling operation is provided either at the rotary table (table drive) or at the swivel (top head drive). The rig also contains a cable called a casing line which is used to raise and lower sections of drill pipe and casing.

In rotary drilling, the borehole size is larger than the casing size. In drift formation, the entire hole is completed before casing is installed. In rock wells, the length of hole to be cased is drilled, the casing is installed, then the bit size is reduced and the rock portion of the well is completed.

Mud rotary utilizes a drilling fluid of bentonite clay and water. The mud serves several purposes: (1) remove cuttings from the drillhole, (2) prevent collapse of the drillhole and reduce water loss to the formations by forming a filter cake on the borehole wall, (3) suspend cuttings when drilling is stopped, (4) cool and clean the drill stem and bit, and (5) lubricate bit bearings and mud pump parts. After the cuttings are allowed to settle in the mud tank, the mud is recirculated via a mud pump to the swivel at the top of the kelly, then down through the drill stem. The mud tank is usually rectangular in shape with a mud volume of 200-800 gallons and may contain several baffles to aid in separation of cuttings from the drilling mud before it enters the pump intake for recirculation. A device known as a sand separator may be used to further remove

sands and other "parasites" from the drilling mud. Samples of cuttings may be obtained directly from the borehole before the fluid and cuttings spill into the mud tank.

Most larger rotary rigs have an air compressor to enable the contractor to also use air as the drilling fluid. The high velocity of the air as it exits the bit is sufficient to blow the cuttings away from the bit and carry them up to the surface where they settle out around the borehole. Air rotary is used primarily for drilling in consolidated (rock) formations. In rock wells with substantial overburden, mud will be used for drilling through the drift, and after the casing is set the drilling operation will be converted to air rotary for completion of the rock portion of the well. Clean water is often used for drilling the rock portion of the hole after setting the casing.

Air hammer drilling, sometimes referred to as down hole drilling, is used extensively in Michigan's hard rock areas. The bit used in this drilling method is essentially a pneumatic hammer operated at the end of the drill stem. Compressed air operates a piston which strikes the top of the bit at a very rapid rate. The cutting tips on the bit are made of tungsten-carbide which are extremely resistant to abrasion. The combined hammering and rotation of the bit results in penetration of hard rock at a rate faster than any other drilling method.

Reverse-circulation is another form of rotary drilling. It differs from conventional hydraulic rotary in that the drilling fluid travels in the opposite direction. The drilling fluid travels up the inside of the drill stem with cuttings, through the pump and is discharged into the settling pond or tank. After cuttings are settled, the drilling fluid flows into the borehole and down to the bit. The pressure of the fluid against the bore hole wall prevents caving. The few reverse-circulation drilling rigs found in Michigan are used primarily for drilling large diameter municipal, industrial, and irrigation wells.

CABLE TOOL DRILLING

Cable tool drilling, also known as percussion drilling or spudding, is a widely used well drilling method in Michigan. Michigan has more cable tool rigs than any other type of drilling machine. Some rigs are combination rotary-cable tool, enabling the operator to use the rotary along with the casing driving ability of the cable tool. Although it is a slower drilling method, the cable tool is less costly and simpler to operate than a rotary drill rig and is suitable for most geologic conditions.

The cable tool operates by raising and dropping a heavy drill string in the drillhole. The drill string, with bit on the lower and rope socket (or swivel socket) on top, is suspended in the hole with a cable. The cable is threaded over the crown sheave located at the top of the mast, down to the walking beam, and onto the cable drum where it is stored. The up-and-down drilling action imparted to the drill stem and cable by the walking beam. The walking beam is pivoted at one end, has a cable sheave at the other end and is connected to the crank gear with a pitman. Rotation of the crank gear causes the walking beam to move up and down. Additional cables called sand lines or casing lines are used to raise and lower casing, bailers, plungers, or other tools.

The rhythmic raising and dropping of the bit loosens up sand or clay and breaks up rock into "cuttings" and mixes them with water added by the driller to form a slurry. The cuttings are then removed from the hole with a dart-valve bailer or other type of bailing device. Formation type is determined by visual inspection of cuttings from the bailer and the drilling contractor's knowledge of the rig's operation, such as the difficulty or ease of drilling the particular formation. The up-and-down motion combined with the left-lay cable and rope socket cause the drill stem and bit to rotate slightly on each vertical stroke. This rotation helps maintain drillhole roundness.

The portion of the drillhole above the bedrock must be cased to prevent caving. Casing is driven into the drillhole with the use of heavy drive clamps bolted onto the drill stem. The drill stem is lowered into the casing until the drive clamps strike the top of the casing. The raising and dropping of the heavy drive clamps and drill stem drives the casing into the drillhole. Prior to driving, a drive shoe of hardened, tempered steel is attached to the bottom of the first length of casing to protect it from damage. The upper end of the casing is protected by inserting a temporary drive cap. The usual cable tool drilling operation involves drilling past the end of the casing, bailing the hole to remove cuttings, driving casing, cleaning the hole, then resuming drilling. Generally, a few feet of open hole is drilled beyond the casing before casing is driven. The driving, drilling, and bailing operations are repeated until the desired depth is reached.

In screened wells, the pull-back method is generally used. This involves driving casing to the bottom of the portion to be screened. A screen of smaller diameter than the casing is placed into the casing. The top end of the screen is fitted with a K-packer or other device which seals between the screen and casing. The screen is pushed to the bottom of the casing, then the casing is "bumped" up to expose the screen to the formation. The bailer is then used to begin development of the screen.

AUGER DRILLING

Continuous-flight, spiral auger well drilling rigs are found in those parts of western, central and northern Lower Michigan where sand is the predominant glacial drift material. In some areas, augers are used to drill the upper portion of the well and then the well is completed with the cable tool method. In other areas of the state, augers are used to drill the entire well.

The auger method utilizes spiral augers, usually in 5 foot lengths. The auger stem is turned by a hydraulically-controlled rotary drive head. After drilling the length of an auger, the auger joint is broken and another 5 foot section is added. Cuttings spiral their way up to the surface where they appear around the borehole, making formation identification relatively simple. If enough clay is present in the formation, the drillhole will remain open when augers are removed. Dry sands and other caving formations may be a problem for the auger driller and will occasionally result in the loss of long flights of augers. When the auger encounters saturated sand (the water bearing formation to be screened), drilling generally can be continued for a short distance but the hole will not remain open in the saturated formation when the augers are removed.

The auger flight is then broken down and removed from the drillhole after drilling the depth of the well or when changing to another type of drilling operation.

Casing is then placed into the drillhole. Some driving of the casing may be necessary because of caving of portions of the drillhole or lack of straightness of the drilled hole. A drillable plug is generally placed in the end of the casing prior to placement in the drillhole. After placement of the casing, it is then filled with water and the screen driven out through the plug and exposed to the water bearing formation. Keeping the casing filled with water prevents heaving of sand into the casing when the plug is knocked out. Another method used by some drillers (but not recommended) is to thread the screen directly to the well casing, thereby installing the screen and casing in one operation. The well is then pumped to remove the fine material from around the screen and to determine if water quality and quantity are suitable.

As the well is being test pumped with a plunger or surge block, the discharged water should be used for washing cuttings into the annulus to seal those parts of the annulus that have not collapsed. Granular bentonite should be added to the cuttings in a proportion of 1 part bentonite to 4 parts cuttings. Whenever the borehole penetrates a clay layer, bentonite shall be used as the grouting material.

DRIVING

Driven wells are common in many areas of Michigan, especially around lakes where groundwater may be close to the surface. Simple installation methods and the low cost of materials make them attractive to homeowners or cottage owners who wish to install their own water supplies. However, since the well point and casing are driven into the ground, soil conditions are a major factor in suitability of the site. The site must be generally sandy and free of boulders or bedrock to be suitable for a driven well. Hard clay, silt, and very fine sand are generally difficult to drive through.

The installation of a driven well often begins by angering a hole with a hand auger or posthole digger as far as possible. A drive point, consisting of a reinforced well screen with a steel point on the end, is coupled to a 5 foot length of galvanized casing. The most common casing size for driven wells is 1-1/4 inch inside diameter. A drive cap is placed on the top of the casing and a heavy weight is used to strike the top of the drive cap, driving the point into the ground. When the drive cap is driven close to the ground and driving cannot be continued, another length of casing is added and driving is resumed. Special drive couplings are used to join sections of casing,

Hand driving is usually accomplished by using a weighted driver consisting of a 3 or 4 foot piece of 3 inch diameter pipe capped on the top end. Extra weight is placed in the top portion of the driver. The driver fits over the casing and is guided by it. Another type of driver has a steel rod on the bottom that slides into the casing through a hole in the drive cap. Raising and dropping the driver is done with the use of handles welded on the sides of the driver. The weighted driver may also be suspended from a tripod and tackle arrangement. The use of a sledge hammer for driving is not recommended since it may result in bent or broken casing from glancing blows.

As driving progresses, penetration becomes increasingly difficult due to friction between the drive point/casing and the soil. Depths beyond 40 feet become difficult when driving by hand. Driving a well is always a gamble since a boulder can easily damage the well point or completely stop the driving. When a driven well attempt is aborted, the casing and well point must often be left in the ground since retrieval is difficult without additional equipment.

A weighted string is used periodically during driving to determine if water has been encountered. When water has been reached, the string will come up wet. The well screen must then be developed to remove the fine material. This is accomplished by pumping and surging. A pitcher pump or shallow well jet pump may be used for development. Pumping and/or surging is continued until the water, which at first is full of sand and silt, runs clear. If an auger was used to start the hole, it is necessary to grout the annular space between the drillhole and casing. Bentonite or neat cement (cement and water mixture) may be used for this purpose.

The major disadvantages of driven wells are as follows: (1) they are generally shallow, therefore more vulnerable to surface or near surface contamination; (2) the screens tend to encrust with carbonates at a faster rate due to their small diameter; and (3) their yield is limited (< 10 gallons per minute [gpm]), since they can be pumped only with a shallow well jet pump or hand pump.

JETTING

Jetting is a drilling method suited for the sandy areas of southwestern Michigan. Jetting remains a popular method for drilling small diameter wells due to its simplicity and inexpensive cost of equipment. Many of the portable, do-it-yourself drilling machines advertised in magazines utilize the jetting method.

Jetting and hollow-rod equipment are quite similar except that drilling water is pumped with the jetting method and the direction of water flow is opposite. The jetting method involves using a high velocity stream of water to break up the formation material and wash the cuttings away. A chisel-shaped bit with holes to serve as nozzles is attached to the end of a string of hollow drill pipe. Water pressure is provided to the nozzles by using a high pressure pump. Water exits from the nozzles and loosens the material being drilled while keeping the bit clean. The bit is raised and lowered and rotated slightly to maintain a round hole. The cuttings are washed to the surface on the outside of the drill pipe and flow into a settling pit or tank. Cutting samples are easily obtained at this point. A 55 gallon drum is often used for this purpose. After cuttings are allowed to settle, the water is recirculated through the pump, swivel, drill pipe and down to the bit. Jetting can also be done without recirculation of the drilling water; however, a continuous supply of water must be available at the site.

The casing is usually installed as the drilling proceeds. A drive shoe is attached to the bottom end of the casing and a drive cap inserted in the top. A drive block clamped to the drill pipe is used to force the casing into the drill hole. The depth of the open hole drilled before casing is installed depends on the type of formation and whether bentonite

has been added to the water as a drilling fluid to keep the hole open. The drilling/driving sequence is extremely time consuming in caving formations, especially at greater depths, since the drill string must be disassembled and removed from the well before driving casing and must be reassembled before resuming drilling.

HOLLOW-ROD DRILLING

Hollow-rod, sometimes referred to as the hydraulic-percussion drilling method, is used throughout Michigan's Lower Peninsula, with the largest concentration of hollow rod rigs being found in the central and southern portion of the state. The hollow-rod is an old drilling method that can be time consuming in some situations, but remains popular due to its simplicity and relatively low cost of equipment. Most hollow-rod wells are 2 inch diameter, but 4 inch casings are installed occasionally. This method is well suited for sand and soft clay formations with relatively few boulders. It can also be used for drilling rock wells, but progress is slowed considerably. Wells several hundred feet in depth have been completed by the hollow-rod method.

The drill string used in hollow-rod drilling is similar to that used in jetting, except that the chisel bit has a ball check valve in it. Water or a clay-water mixture is kept in the annular space between the drill rods and well casing to help prevent the uncased portion of the hole from collapsing. The water is supplied to the annulus by gravity intake from a small mud tank. A 55 gallon drum is often used as a settling tank.

Drilling is done by lifting and dropping the drill stem and bit. The drill pipe used has triple wall thickness to add weight to the drill string. The drill string is also rotated slightly by hand during each stroke to maintain a round drill hole. As the bit drops, the ball check opens and mud and cuttings enter the hollow drill rods. On the upstroke, the check valve closes and keeps the cuttings in the drill rods.

Eventually the drill rods fill up and the slurry is discharged into the mud tank at the surface where the cuttings settle out. Samples of cuttings can easily be obtained from the mud tank. The continuous reciprocating drilling motion maintains circulation of the drilling fluid from the bit, up the drill rods to the mud tank, from the mud tank into the annulus, and down to the bit. The direction of flow is opposite that in the jetting operation and no pressure pump is required.

Casing is driven as drilling progresses by clamping a weighted drive block to the drill rods. When another length of casing is added, the drill rods must be disassembled and removed from the hole. The drill rods are then reassembled, casing is driven, the drive block is removed and drilling is resumed. Close observation of formation samples and water/drilling fluid circulation by the drilling contractor is essential to determine when groundwater has been encountered. When a water-bearing strata is reached, drilling fluid is usually lost to the formation. At this point, it is necessary to install a well screen, if in an unconsolidated formation, and begin the well development process. Hollow-rod rigs are equipped with walking beams, thus a plunger is most generally used to develop the well.

COMPARISON OF WATER WELL DRILLING METHODS

	Cable Tool	Rotary	Auger	Hollow Rod	Jetting	Driving
Other names	Percussion Spudding Churn Drill	Hydraulic rotary (mud rotary, air rotary, down hole hammer, reverse circulation)	Continuous-flight auger	Hydraulic- percussion	Jet-percussion	Driven well point, stab well
Drilling motion	Raising-dropping of drill stem and bit	Rotating drill string and bit	Rotating of augers and bit	Raising-dropping of drill rods and bit	Jetting action of water exiting bit	Well point and casing driven into ground to displace soil material
Drill string	Cable with suspended drill string (rope socket, drill stem, bit)	Swivel-kelly drill rods-stabilizer-bit (top head or table drive)	Top head drive- auger flights-bit	Swivel-drive block drill rods-bit	Swivel-drive block drill rods-bit	Drive cap-5 foot casing lengths drive point
Casing installation	As drilling proceeds	After drillhole is complete	After drillhole is complete	As drilling proceeds	As drilling proceeds	As driving proceeds
Casing installation method	Driven	Gravity (some driving)	Gravity (some driving)	Driven	Driven	Driven
Drilling fluid type	Water	Bentonite water (mud rotary), air (air rotary or down hole hammer), water (rev. rotary)		Down annulus-up drill rods	Down drill rods-up annulus	
Direction of fluid flow	Stationary	Down drill rods-up annulus (opposite in rev. rotary)		Down annulus-up drill rods	Down drill rods-up annulus	
Retrieval of cuttings	Bailer	Flow into mud pit with drilling fluid	Deposited on ground surface	Flow into mud pit with drilling fluid	Flow into mud pit with drilling fluid	

OTHER DRILLING METHODS

DOWNHOLE HAMMER

Use of the down hole air hammer with rotary equipment provides a combined percussion-rotary method that penetrates rapidly in consolidated formations. Test holes are usually 6 inches in diameter when using this method. In most cases, however, conventional water-based drilling fluids must be used with a roller bit when drilling through unconsolidated overburden above bedrock. Exceptions to this occur when an air hammer is used to drive the casing after materials are blown out of the casing or when the rig is equipped with a casing driver.

This method allows contractors to drill more wells, and be able to drill them deeper and faster. Instead of using a mud pump, they use compressed air.

DUAL TUBE ROTARY

In this method, the drill pipe and bit are joined and advanced simultaneously. The conventional top drive drills the open hole and the lower rotary drive is used to set casing without any requirement for casing hammers, under-reamers, or drilling mud. Advantages of this drilling method are: ability to drill in tough conditions, quicker penetration rates, straighter holes, and a large compressor is not needed because the lower drive operates on hydraulics.

Either air or water can be used as the drilling fluid in this modification of reverse circulation technique. There is usually no grinding of cuttings, and the drilling fluid, if not air, can be clear water.

SONIC

A sonic drill uses high frequency mechanical oscillations, developed in the special drill head, to transmit resonant vibrations and rotary power through the drill tooling to the drill bit. The operator controls the frequencies to suit the specific conditions of the geology. An air spring in the drillhead isolates the vibrations from the rest of the rig. The vibrations fluidize the soil particles at the bit face, allowing fast and easy penetration in most geological formations including boulders and rock.

One of the main advantages of the sonic drill is its ability to produce continuous core samples of both unconsolidated and consolidated formations with detail and accuracy. The core samples can be analyzed to provide a precise and detailed stratigraphic profile of any overburden condition including dry or wet saturated sands and gravels, cobbles and boulders, clays, silts and hard tills.

DIRECTIONAL DRILLING

Directional drilling is the technique of drilling at an angle from the vertical by deflecting the drill bit. Directional wells are drilled for a number of reasons: to develop and offshore lease from one drilling platform; to reach a payzone beneath land where drilling cannot be done, e.g., beneath a railroad, cemetery or lake, or to drill around a blockage in an existing wellbore.

A pilot hole is drilled under the natural feature and then backreamed to make the hole large enough to accommodate the pipe. Once the hole is large enough the pipe is pulled through the hole.

WATER WELL DRILLING METHODS - QUICK FACTS

CABLE TOOL

Definition: Spudding action with percussion or grinding due to heavy tool weight.

ADVANTAGES

Inexpensive equipment

- 1/5 the cost of rotary rig
- Less grouting equipment needed.
- Large water truck unnecessary.
- Significantly lower fuel consumption.
- Lower operating cost.

Limited Tooling Required

- Longer bit life – bits can be resurfaced.
- Less expensive tooling – repairable bailers.
- Used items readily available.

Less Material Removed During Drilling

- Generally no oversized borehole.
- Geologic material removed from casing inside diameter (I.D.)
- Lighter soils can be bailed from casing.

DISADVANTAGES

Slow Drilling Speed

- Bedrock drilling: 1/7 as fast as rotary drilling.
- Glacial drift drilling: 1/5 as fast as rotary drilling.

Depth Limitations with Single Casing String

- Driving generally difficult in caving formations.
- Ability to drive casing is limited by tool weight and ground friction.

Outer Casing Needed for Gravel Packing or Full Length Grouting

- 3 to 4 inch larger outer casing needed to maintain annulus and must be extracted during grouting.

Steel Casing Material Only

- PVC casing cannot be used unless installed in oversized borehole without driving.

APPLICATIONS

4 inch through 24 inch – 4 to 6 inch I.D. most common

Repair Work

- Cable tool rigs ideal for casing reaming, screen replacement, and development.

CABLE TOOL PRINCIPLES

Drilling Motion

- Raising and dropping of drill stem and bit.
- Percussion or spudding action.
- Inefficient drilling motion (minimal bit/formation contact).

Casing Installation Method

- Casing driven as drilling proceeds, with weight added to drill stem.
 - Borehole sometimes drilled ahead of casing.
 - Casing driven through unconsolidated soils with no removal of material until driving completed.
 - Casing occasionally installed in oversized borehole.

Drilling Fluid

- Water (chlorinated).
- Bentonite sometimes added.

Cuttings Removal

- Bailer lowered and raised.
- Dart-valve type bailer – common in clay.
- Flat-bottom/flapper type bailer – common in sands.
- Suction bailer or sand pump.

Drilling Tools

- Socket – stem – bit
- Jars for special applications.

Fishing Tools

- For retrieving lost tools.
- Slip sockets (overshots).
- Spear-types for casing or cable retrieval.

JETTING AND HOLLOW ROD

Definition: Liquid circulation with percussion action.

ADVANTAGES

Inexpensive equipment

- 1/5 the cost of rotary rig.
- Less grouting equipment needed.
- Large water truck unnecessary.
- Significantly lower fuel consumption.
- Lower operating cost.

Limited Tooling Required

- Longer bit life – bits can be resurfaced.
- Less expensive tooling – repairable bailers.
- Used items readily available.
- Many tools fabricated.

Less Material Removed During Drilling

- Generally no oversized borehole.
- Geologic material removed from casing I.D.

DISADVANTAGES

Slow Drilling Speed

- Bedrock drilling: uncommon – requires heavy drill bar.

- Bedrock drilling: 1/7 as fast as rotary drilling.
- Glacial drift drilling: 1/5 as fast as rotary drilling.
- Limited use in gravel formations.

Depth Limitations with Single Casing String

- Driving generally difficult in caving formations.
- Ability to drive casing is limited by tool weight and ground friction.

Outer Casing Needed for Gravel Packing or Full Length Grouting

- 3 to 4 inch larger outer casing needed to maintain annulus and must be extracted during grouting.

Steel Casing Material Only

- PVC casing cannot be used unless installed in oversized borehole without driving.

APPLICATIONS

2 inch through 4 inch – most common

Limited above 4 inch.

Repair Work

- Jetting rigs ideal for screen replacement and development.

JETTING AND HOLLOW ROD PRINCIPLES

Drilling Motion

- Jetting: high velocity jetting action of water existing bit.
- Hollow rod: Raising and dropping (spudding action) of weight, swivel, drill rods, and chisel bit.

Casing Installation Method

- Casing driven as drilling proceeds, with weight added to drill stem.
 - Borehole sometimes drilled ahead of casing.
 - Casing driven through unconsolidated soils with no removal of material until driving completed.
 - Casing occasionally installed in oversized borehole.

Drilling Fluid

- Water (chlorinated).
- Bentonite sometimes added.

Fluid Flow

- Jetting: Down drill rods and up annulus between drill rod and casing. Requires pump to create high pressure jetting action and move cuttings.
- Hollow rod: Gravity down annulus between casing and drill-pipe (opposite direction to jetting). Ball check/chisel bit used – cuttings move up inside of drill pipe.

Cuttings Removal

- Jetting: Cuttings washed up on outside of drill pipe.
- Hollow rod: Cuttings pumped up inside of drill pipe with check valve/spudding action.

Drilling Tools

- Heavy wall pipe (bottom length), swivel, and weight (optional).
- Jetting: chisel bit.
- Hollow rod: chisel bit with ball check valve.

ROTARY

Definition: Liquid circulation with rotary action and down pressure.

ADVANTAGES

Speed of Drilling

- 5 to 7 times faster than cable tool.
- Capable of several hundred feet per day (dependent upon type of geologic material penetrated).

Options of Well Design

- Conventional – telescoped screen.
- Casing-sized screen and separated screens.
- Filter-packing (gravel-packing) to enhance formation production.
- Downhole casing hammer method.

Grouting

- Oversized borehole requires grouting of annular space surrounding casing.
- Most adaptable to various grout placement methods.
- Practical for grout placement thru casing.

DISADVANTAGES

Cost of Equipment

- Five times as costly as a cable tool or jetting rig.
- Bit cost and tooling more expensive.

Maintenance and Support

- Much more extensive and costly than cable tool.
- Higher fuel consumption.
- Water truck needed (1,000 to 2,500 gallon tank).

ROTARY PRINCIPLES

Casing Installation

- Installed by setting casing in an oversized borehole.
- Limited driving.
- Capable of installing either PVC plastic or steel casing.

Drilling Fluid

- Used to stabilize borehole wall to prevent caving during drilling, minimize water loss to formation, lubricate bit, and remove cuttings.
 - Mud Rotary
 - Bentonite (powdered) and water (chlorinated).
 - Water without bentonite occasionally used.
 - Viscosity (thickness) of drilling fluid measured with Marsh funnel.
 - Air Rotary
 - Compressed air and 3-6 gpm water.
 - Foam additives to improve hole cleaning.
 - Reverse Rotary
 - Primarily water (large volume and several hundred gpm)
 - Air injection commonly used to speed removal of cuttings.

Drilling Motion

- Rotation of drill rods and bit.
- Downpressure applied.
- Percussion available in downhole hammer.

Drill Tools

- Top Head – Rotary drive and downpressure applied to top of drill rods.
- Table Drive – Rotary drive applied to drill rods via Kelly bar and table. Downpressure applied at top of Kelly with pull-down chains on mast.

Fluid Flow and Cuttings Removal

- Air and Mud Rotary – Down drill rods and up annular space between drill rods and borehole. Cuttings settle out in mud tank.
- Reverse Rotary – Gravity flow down annular space between drill rods and borehole and up inside of flanged drill pipe with assistance from air lift.

ROTARY DRILLING ACCESSORIES

Mud Pump

- Used to circulate drilling fluid.
- Most common types: piston, centrifugal, diaphragm, positive displacement.

Swivel

- Transfer point from stationary fluid hose to rotating drill pipe.
- Most common types: top feed and side feed.

Stabilizer

- Pipe added to bottom of drill rods to maintain uniform hole diameter and straightness.
- Types: solid casing outside diameter (O.D.), ribbed, flow-thru
- Stabilizer lengths vary.

Bit

- Attached to end of drill rods or stabilizer.
- Most common type: tricone roller bit (straighter hole than bicone).
- Button bits – flat or conical.
- Paddle or blade bits – preferred for drilling clays.
- Pneumatic hammers for air rotary bedrock drilling.

Mud Tub (also called Mud Tank or Mud Pit)

- Used to settle cuttings from drilling fluids and prevent carryover (recirculation) of cuttings.
- Containment of drilling fluid.
- Mixing of drilling fluid.
- Measurement of pumping rates and circulation rates.

Mud Mixer

- Uses venture principle to mix powdered bentonite or polymers with water to make drilling fluid.
- Usually shop built by contractor.

Desander

- Centrifugal separation of sand from drilling fluid.
- Saves pump and swivel wear.
- Maintains proper solids level in drilling fluid.
- Prevent carryover of cuttings.

Casing Hammer

- Drives steel casing during rotary drilling process.
- Pneumatically operated.

Compressor

- To provide air course for air drilling, development and pumping.

AUGER

Definition: Rotary action with down pressure with augers.

ADVANTAGES

Speed

- Fast for shallow holes without cobbles or gravel and with low water table.
- Auger/cable tool or jetting combination rigs are common.

Limited Equipment

- Less expensive than rotary.
- Minimal amount of equipment needed.

DISADVANTAGES

Limited Depth

- Poor results in caving formations, gravel, or high water table.
- Less than 100 feet – most practical.

Difficult Grouting

- Hard to maintain annulus in some formations.

DRY HOLE AUGER

Drilling Motion

- Rotation of spiral auger flights with downpressure as needed.

Drilling Tools

- Auger flights – generally 5 foot lengths.
- Bit types: auger and carbide tooth bit

Casing Installation

- After borehole is drilled.
- Placed by gravity into open borehole.

Drilling Fluid

- None used with auger drilling.

Fluid Flow

- Natural water table.

Cuttings Removal

- Up outside of auger flights.
- Cuttings deposited on ground surface.
- Manually removed from around well bore.

HOLLOW STEM AUGER

Application

- Environmental and monitoring wells.
- Geotechnical borings.

How Used

- Casing and screen installed through augers.
- Filter packing and grouting done before removing augers.

WATER WELL COMPONENTS

Borehole

Borehole is a vertical boring to reach aquifer (water bearing geologic material). In a well terminating into rock, an open borehole will extend beyond the bottom of the well casing.

Well Seal

Well seal is a mechanical device to prevent contamination from entering well casing that is installed after well completion. All well caps and seals shall be weathertight, tightly secured, and vermin proof.

Casing

Well casing is steel or plastic pipe installed to keep borehole wall from collapsing and houses the submersible pump and drop pipe.

Comparison of PVC plastic casing and steel casing:

<u>PVC</u>	vs.	<u>Steel</u>
Noncorroding		Corrodes
Lower strength		Higher strength
Fewer water quality complaints		Rusty water
Rotary construction only		Suitable for any drilling method

Grout

Grout is impermeable cement or clay placed in annular space between borehole and casing to prevent well contamination, maintain separation of aquifers, and preserve artesian aquifers.

Filter pack

Filter pack is silica sand often placed around the outside of the screen for filtration and stabilization. The main objective to filter packing is to install a material more permeable than the native formation into the area immediately surrounding the well screen. Filter pack not only prevents fine sands from entering the well screen, it also stabilizes the borehole.

The benefits of filter packing are:

- ⇒ Greater porosity
- ⇒ Higher hydraulic conductivity
- ⇒ Reduced drawdown
- ⇒ Higher yield
- ⇒ Reduced entrance velocity
- ⇒ Faster development
- ⇒ Easier grouting
- ⇒ Longer well life
- ⇒ Improved well rehabilitation
- ⇒ Reduced sand pumping

Packer

A neoprene packer (often called a K packer) is a device that seals space between casing and telescoped screen to keep sand out of well. The packer is attached directly to either the top of the well screen or the top of a riser pipe. Lead packers are no longer allowed in Michigan.

Screen

A well screen is a filtering device that serves as the intake portion of wells constructed in unconsolidated or semiconsolidated aquifers. A screen permits water to enter the well from the saturated aquifer, prevents sediment from entering the well, and serves structurally to support the unconsolidated aquifer material.

Slot openings have been designated by numbers that correspond to the width of the openings in thousandths of an inch. A No.10 slot, for example, is an opening of 0.010 inch. Slot size may also be expressed in metric units; for example, 0.010 inch equals 0.25 millimeter (mm). For small-diameter screens covered with wire mesh, the number of openings in the mesh per inch are designated by gauze numbers.

Geological Material	Slot Size	Opening (inches)	Opening (mm)	Gauze Size
Clay & Silt	-	0.003	0.10	-
Fine sand	6	0.006	0.15	90
	7	0.007	0.18	80
	8	0.008	0.20	70
	10	0.010	0.25	60
Medium sand	12	0.012	0.30	50
	15	0.015	0.40	-
	18	0.018	0.45	40
	20	0.020	0.50	-
Coarse sand	25	0.025	0.65	30
	35	0.035	0.90	20
Very coarse sand	50	0.050	1.27	-
Very fine gravel	90	0.090	2.29	-
Fine gravel	150	0.150	3.81	-
	250	0.250	6.35	-
	375	0.375	9.52	-

When selecting the proper screen to install, the following selection criteria need to be considered:

- * Maximize the percent of open area.
- * Nonclogging openings.
- * Corrosive resistance.
- * Column and collapse strength.
- * Screen opening (slot size) based on aquifer material.
- * Screen diameter that provides a water entrance velocity of less than .1 foot/second.

Fact or Fiction? – “*Doubling the well diameter appreciably increases well yield.*”

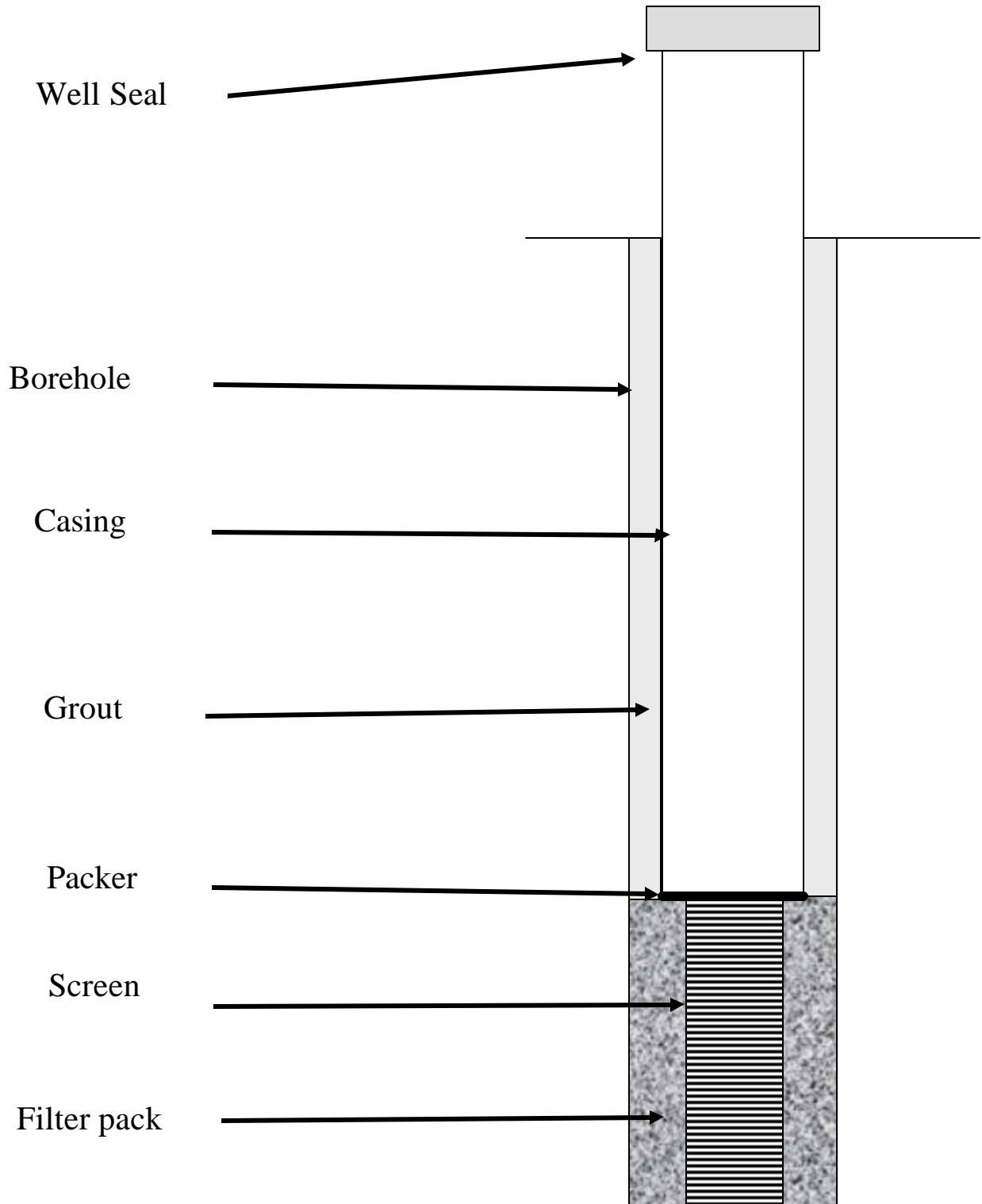
Answer

Doubling the well diameter increases the well yield only 10 percent.

Doubling the screen length increases the well yield 100 percent.

TYPICAL WELL CROSS SECTION

NOTE: If the well terminated into bedrock, the packer, filter pack, and screen would not be present, and an open borehole would extend below the casing.



TYPES OF WATER WELLS

Drilled Wells

- Terminate in glacial drift (sand, gravel) or bedrock.
- Constructed using rotary, cable tool, jetting, hollow rod, or auger rigs.
- 2 inches or larger casing (domestic wells 4-5 inch).
- Casing material can be steel or PVC plastic.
- Installed by well drilling contractors.
- More common than driven or dug wells.
- Most are greater than 50 feet deep.
- Most sanitary type.



Driven Wells

- Installed in glacial drift only.
- Cannot be driven into bedrock.
- Well point driven into ground with post driver, tripod with weight or sledge hammer.
- 1.25-2 inches diameter.
- Most installed by owner.
- Common around lakes and high water table areas.
- Most are less than 35 feet deep and have a limited yield (less than 7gpm).
- More susceptible to contamination than drilled wells.



Dug Wells

- Historical type of wells, originally drilled in Michigan
- Larger diameter (18-48 inch).
- Curbing material is usually concrete crocks with loose joints.
- Water enters well through loose casing joints.
- Older dug wells were hand-dug.
- Some were installed with bucket augers.
- Low well yield, but casing stores 100's of gallons.
- Highly vulnerable to contamination (85 percent positive for coliform based on 1994 CDC study).



Large Diameter Low Yield Wells

- Installed in low yield areas ("Thumb" and SE Michigan)
- Casing material is slotted fiberglass (National Sanitation Foundation certified).
- Upper 25 feet of casing is grouted.
- More sanitary than old dug wells
- Requires unique pitless adapter (due to corrugated casing wall).
- Only allowed under a deviation where conventional wells can not be drilled.